參考文獻

[1] S. Hara, R. Prasad, "Overview of Multicarrier CDMA," IEEE Communications Magazine, Dec.1997,pp.126-133

[2] A. Acx, R.L. Aguiar, " Reference scenario specification: final description", IST MATRICE Project, D1.4, July 2003

[3] S. Abeta, H.Atarashi, M. Sawahashi, "Coherent multicarrier/DS-CDMA and MC-CDMA for broadband packet wireless access ", IEEE Vehicular Technology Conference Proceedings, May 2000, pp.1918-1922

[4] Jiho Jang, Kwang Bok Lee, "Effects of frequency offset on MC/CDMA system performance",IEEE Communications Letters, July 1999, pp.196-198

[5] H. Steendam, M. Moeneclaey, "The effect of carrier frequency offsets on downlink and uplink MC-DS-CDMA", IEEE Selected Areas in Communications, Dec. 2001, pp.2528-2536

[6] H. Steendam, M. Moeneclaey, "Comparison of the sensitivities of MC-CDMA and MC-DS-CDMA to carrier frequency offset", IEEE Communications and Vehicular Technology, 2000, Oct. 2000, pp.166-173

[7] A.C. McCormick, P.M. Grant, J.S. Thompson, "A Carrier Frequency Offset Correction Scheme for MC-CDMA", IEEE Vehicular Technology Conference, May 2001, pp.1689-1692

[8] Z. Li, M. Latva-aho, "BER performance evaluation for MC-CDMA systems in Nakagami-m fading",IEEE Electronics Letters, Nov. 2002, pp.1516-1518

[9] M. Abdel-Hafez, Z. Li; M. Latva-aho, "Performance of uplink and downlink MC-CDMA equalizers in frequency selective Nakagami fading channels",

IEEE Spread Spectrum Techniques and Applications,Sept. 2002, pp.385-389

[10]L. L. Yang, L. Hanzo, "Performance of generalized multicarrier DS-CDMA over Nakagami-m fading channels", IEEE transactions Communications, June 2002, pp.956-966

[11]S. Chatterjee, W.A.C. Fernando, M.K. Wasantha, "Adaptive modulation based MC-CDMA systems for 4G wireless consumer applications " IEEE Consumer Electronics Transactions on , Nov. 2003, pp.995-1003

[12]Z. Zhongpei, Z. Yahong, Y. Yan,"Adaptive modulation and power allocation for multicarrier DS/CDMA Communications", IEEE Circuits and Systems and West Sino Expositions, July 2002, pp.243-246

[13]Richard van Nee and Ramjee Prasad, *OFDM for Wireless Multimedia Communications*, Artech House, 2000

[14]S.B Weistein, Paul M. Ebert. "Data Transmission by Frequency-Division Multiplexing Using the Discrete Fourier Transform",IEEE Transactions on Communications, Oct. 1971, pp.628-634

[15]V. Fischer, A. Kurpiers, D. Karsunke, "ICI Reduction Method for OFDM Systems",8th International OFDM-Workshop 2003,Conference Proceedings

[16]J.-J. van de Beek, O. Edfors, M. Sandell, S.K. Wilson, P.O. Borjesson, "On channel estimation in OFDM systems", IEEE Vehicular Technology Conference, July 1995, pp.815-819

[17]M.J.F.-G. Garcia, S. Zazo, J.M. Paez-Borrallo, "Pilot Patterns for Channel Estimation in OFDM",IEEE Electronics Letters, June 2000, pp.1049-1050

[18]Rappaport, S. Theodore, *Wireless Communications:Principles and Practice*,

Prentice-Hall, 2002

[19]Simon Haykin, *Adaptive Filter Theory*, Fourth Edition, Prentice-Hall, 2002

[20]H.Meng-Han,W. Che-Ho, "Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels", IEEE Transactions on Consumer Electronics, Feb. 1998, pp.217-225

[21]Liu, Hui, "*Signal processing applications in CDMA communications*", Artech House, 2000

[22]Stuber, L. Gordon, "*Principles of Mobile Communications*", Kluwer Academic, 2001

[23]N. Yee, J.P. Linnartz and G. Fettweis, "Multi-Carrier CDMA in Indoor Wireless Radio Networks", Proceedings PIMRC'93, Yokohama, Japan, 1993, pp109-113

[24]S. Kaiser, "On the Performance of Different Detection Techniques for OFDM-CDMA in fading channels", IEEE Global Telecommunications Conference 1995, GLOBECOM'95, pp.2059-2063 volume.3

[25]Han Zhu, "Study of DS-CDMA, RAKE Receiver and Proposal for a Multicarrier DS-CDMA System", CSHCN Technical Reports, 1999

[26]E.A. Sourour, M. Nakagawa, "Performance of orthogonal multicarrier CDMA in a multipath fading channel", IEEE Communications Transactions on, Mar. 1996, pp.356-367

[27]P. Marques, A. Gameiro, J. Fernandes, "Pilot-Aided Channel Estimation for MC-CDMA in Beyond 3G Wireless Systems", IST Mobile Communications Summit, Aveiro, 15-18 June 2003

[28]A.-G. Acx, F. Berens, "Specification of the performance evaluation methodology ant the target performance", IST MATRICE Project, D1.3, Jan. 2003

[29]W. Chun-Sheng, "Pilot based fading channel estimation in OFDM", NCTU Master Thesis, 2003

[30]S. Abeta, H. Atarashi, and M. Sawahashi, "Broadband Packet Wireless Access Incorporating High-Speed IP Packet Transmission", IEEE VTC2002 Fall, Sept.2002, pp.24-28

[31]N. Yee, J.P. Linnartz, and G.Fettweis, "Multi-carrier CDMA in indoor wireless radio network," Proc. IEEE International Symposium on Personal, Indoor, and Mobile Radio Communication(PIMRC), pp. 109-113,1993.

附錄: MC-CDMA 位元錯誤率推導

- EGC

將式(4.2-19)代入式(4.2-11)可得[31]:

$$\begin{aligned} v_0 &= d_0\sum_{i=0}^{N-1}|H[i]| + \sum_{k=1}^{K-1} d_k\left(\sum_{i=0}^{N-1} c_k[i]c_0[i]|H[i]|\right) + \sum_{i=0}^{N-1} n[i]\frac{H^*[i]}{|H[i]|}c_0[i] \\ &= d_0\sum_{i-0}^{N-1}\rho_i + \sum_{k=1}^{K-1} d_k\left(\sum_{i=0}^{N-1} c_k[i]c_0[i]\rho_i\right) + \sum_{i=0}^{N-1} n[i]c_0[i]e^{-j\theta_i} \end{aligned} \quad \text{(A-1)}$$

令 $Q[i] = c_l[i]c_m[i]$ (A-2)

由華氏碼的正交性可得:

$$\sum_{i=0}^{N-1} Q[i] = 0 \text{ , for } l \neq m \quad , Q[i] \in \{-1, 1\} \quad \text{(A-3)}$$

由上式可知 $\{Q[i] | i = 0,\ldots, N-1\}$ 此集合包含各 $\frac{N}{2}$ 個值為 1 與-1 的子集合:

$$\begin{aligned} & Q[a_j] = 1,\ Q[b_j] = -1, \quad \text{for } j = 0,\ldots,\frac{N}{2}-1 \\ & \{a_j\} \cup \{b_j\} = \{0,\ldots, N-1\} \end{aligned} \quad \text{(A-4)}$$

由式(A-2)與式(A-4)可改寫式(A-1)為:

$$\begin{aligned} v_0 &= d_0\sum_{i-0}^{N-1}\rho_i + \sum_{k=1}^{K-1} d_k\left(\sum_{j=0}^{\frac{N}{2}-1}\rho_{a_j} - \sum_{j=0}^{\frac{N}{2}-1}\rho_{b_j}\right) + \sum_{i=0}^{N-1} n[i]c_0[i]e^{-j\theta_i} \\ &= S_0 + I_M + \tilde{n} \end{aligned} \quad \text{(A-5)}$$

其中，雜訊變異數(variance) $\sigma_{\tilde{n}}^2$ 為: $\sigma_{\tilde{n}}^2 = N\cdot E\left[n[i]n^*[i]\right] = N\sigma_n^2$ (A-6)

而多用戶干擾I_M可視為兩組高斯隨機變數(Gaussian random variables)的總和，當 N 夠大，我們可用中央極限定理將其逼近為平均為零的高斯變數，其變異數為:

$$\begin{aligned}\sigma_{I_M}^2 &= (K-1)N\sigma_{\rho_i}^2 = (K-1)N\left(E\left[\rho_i^2\right]-E^2\left[\rho_i\right]\right)\\ &= (K-1)N(2-\frac{\pi}{2})\sigma^2\end{aligned} \tag{A-7}$$

則信號-干擾雜訊比(SINR)為:

$$\gamma = \frac{S^2}{\sigma_{I_M}^2+\sigma_{\tilde{n}}^2} = \frac{\left(\sum_{i=0}^{N-1}\rho_i\right)^2}{(K-1)N(2-\frac{\pi}{2})\sigma^2+N\sigma_n^2} \tag{A-8}$$

由大數法則(Law of large numbers)，$\sum_{i=0}^{N-1}\rho_i$可近似為$N\cdot E\left[\rho_i\right]$，故我們可由 SINR 導出 BPSK 系統位元錯誤率:

$$\begin{aligned}P_e &= \frac{1}{2}erfc\left(\sqrt{\frac{\gamma}{2}}\right) = \frac{1}{2}erfc\left(\sqrt{\frac{1}{2}\frac{N^2E^2\left[\rho_i\right]}{(K-1)N(2-\frac{\pi}{2})\sigma^2+N\sigma_n^2}}\right)\\ &= \frac{1}{2}erfc\left(\sqrt{\frac{\pi}{4}\frac{N^2\sigma^2}{(K-1)N(2-\frac{\pi}{2})\sigma^2+N\sigma_n^2}}\right)\\ &= \frac{1}{2}erfc\left(\sqrt{\frac{\pi}{4}\frac{1}{\frac{(K-1)}{N}(2-\frac{\pi}{2})+\frac{\sigma_n^2}{N\sigma^2}}}\right)\end{aligned} \tag{A-9}$$

- MRC

將式(4.2-19)及式(A-4)代入式(4.2-9)可得[31]:

$$\begin{aligned} v_0 &= d_0 \sum_{i=0}^{N-1} \rho_i^2 + \sum_{k=1}^{K-1} d_k \left(\sum_{i=0}^{N-1} c_k[i] c_0[i] \rho_i^2 \right) + \sum_{i=0}^{N-1} n[i] c_0[i] \rho_i e^{-j\theta_i} \\ &= d_0 \sum_{i=0}^{N-1} \rho_i^2 + \sum_{k=1}^{K-1} d_k \left(\sum_{j=0}^{\frac{N}{2}-1} \rho_{a_j}^2 - \sum_{j=0}^{\frac{N}{2}-1} \rho_{b_j}^2 \right) + \sum_{i=0}^{N-1} n[i] c_0[i] \rho_i e^{-j\theta_i} \\ &= S_0 + I_M + \tilde{n} \end{aligned} \tag{A-10}$$

其中，雜訊變異數(variance) $\sigma_{\tilde{n}}^2$ 為:

$$\sigma_{\tilde{n}}^2 = N\sigma_n^2 \cdot E\left[\rho_i^2\right] = 2N\sigma_n^2\sigma^2 \tag{A-11}$$

接著，如同在 EGC 的分析中，當 N 夠大時，我們可用中央極限定理將多用戶干擾 I_M 逼近為平均為零的高斯變數，其變異數為:

$$\begin{aligned} \sigma_{I_M}^2 &= (K-1)N\sigma_{\rho_i^2}^2 = (K-1)N\left(E\left[\rho_i^4\right] - E^2\left[\rho_i^2\right]\right) \\ &= (K-1)N\left(8\sigma^4 - 4\sigma^4\right) = 4(K-1)N\sigma^4 \end{aligned} \tag{A-12}$$

則信號-干擾雜訊比(SINR)為:

$$\begin{aligned} \gamma &= \frac{S^2}{\sigma_{I_M}^2 + \sigma_{\tilde{n}}^2} = \frac{\left(\sum_{i=0}^{N-1} \rho_i^2\right)^2}{4(K-1)N\sigma^4 + 2N\sigma_n^2\sigma^2} \\ &\simeq \frac{N^2 \cdot E^2\left[\rho_i^2\right]}{4(K-1)N\sigma^4 + 2N\sigma_n^2\sigma^2} = \frac{4N^2\sigma^4}{4(K-1)N\sigma^4 + 2N\sigma_n^2\sigma^2} \\ &= \frac{1}{\frac{K-1}{N} + \frac{\sigma_n^2}{2N\sigma^2}} \end{aligned} \tag{A-13}$$

由 SINR 導出 BPSK 系統之位元錯誤率:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{\gamma}{2}}\right) = \frac{1}{2} erfc\left(\sqrt{\frac{1}{2}\frac{1}{\frac{K-1}{N}+\frac{\sigma_n^2}{2N\sigma^2}}}\right)$$
$$= \frac{1}{2} erfc\left(\sqrt{\frac{1}{2\frac{K-1}{N}+\frac{\sigma_n^2}{N\sigma^2}}}\right) \tag{A-14}$$